

DELAY REDUCTION: CURRENT STATUS

EDMUND FANTINO, RAY A. PRESTON, AND ROGER DUNN

UNIVERSITY OF CALIFORNIA AT SAN DIEGO AND SAN DIEGO STATE UNIVERSITY

Delay-reduction theory states that the effectiveness of a stimulus as a conditioned reinforcer may be predicted most accurately by the reduction in time to primary reinforcement correlated with its onset. We review support for the theory and then discuss two new types of experiments that assess it. One compares models of choice in situations wherein the less preferred outcome is made more accessible; the other investigates whether frequency of conditioned reinforcement affects choice beyond the effect exerted by frequency of primary reinforcement.

Key words: choice, conditioned reinforcement, rate of primary reinforcement, delay-reduction theory, incentive theory, melioration, concurrent-chains schedules, tandem schedules, key peck, pigeons

One score and 4 years ago marked the birth of delay-reduction theory (DRT). It seems appropriate to review its present status both in relation to other theories of conditioned reinforcement and in terms of its future evolution.

According to DRT, the effectiveness of a stimulus as a conditioned reinforcer may be predicted most accurately by calculating the reduction in the length of time to primary reinforcement measured from the onset of the preceding stimulus (Fantino, 1969, 1977, 1981; Fantino & Davison, 1983; Killeen & Fantino, 1990; Squires & Fantino, 1971). The simplest form of the parameter-free DRT may be stated as:

Reinforcement strength of Stimulus A

$$= f\left(\frac{T - t_A}{T}\right), \quad (1)$$

where t_A is the temporal interval between the onset of Stimulus A and primary reinforcement and T is the total time between reinforcer presentations. Expressed differently, the greater the improvement (in terms of temporal proximity or waiting time to reinforcement) that is correlated with the onset of a stimulus, the more effective that stimulus will be as a conditioned reinforcer. Although the hypothesis has been extended to areas such as self-control (Ito & Asaki, 1982; Navarick & Fan-

tino, 1976), elicited responding (Fantino, 1982), three-alternative choice (Fantino & Dunn, 1983), observing (Case & Fantino, 1981; Fantino & Case, 1983), operant analogues to foraging (Abarca & Fantino, 1982; Fantino & Abarca, 1985), percentage reinforcement (Spetch & Dunn, 1987), and the serial-position effect in short-term memory (Wixted, 1989), the hypothesis was first developed to account for choice between two variable-interval (VI) schedules of reinforcement in the concurrent-chains procedure developed by Abarca (1960, 1969) and Herrnstein (1964).

The Squires and Fantino (1971) form of DRT weights delay reduction by the overall rate of primary reinforcement arranged for each alternative so that

$$\begin{aligned} \frac{B_L}{B_L + B_R} &= \frac{r_L(T - t_L)}{r_L(T - t_L) + r_R(T - t_R)} \\ &\quad \text{for } t_L < T \text{ and } t_R < T, \\ &= 1, \quad \text{for } t_L < t, t_R > T, \\ &= 0, \quad \text{for } t_L > T, t_R < T, \end{aligned} \quad (2)$$

where B_L and B_R are the choice responses on the left and right keys, respectively, measured in the concurrently available initial links (choice phase); r_L and r_R are the overall rates of primary reinforcement on the left and right keys, respectively; T is the average overall time to primary reinforcement measured from the onset of the choice phase; and t_L and t_R are the average times (or delays) during the terminal links (or outcome phase) on the left and right keys, respectively. The term $(T - t_x)$ represents the degree to which a terminal-link stimulus is correlated with a reduction in time to primary reinforcement. The inclusion of the terms r_L and r_R acknowledges the fact that

Ray A. Preston is now at the Department of Environmental Medicine, University of Rochester Medical Center, Rochester, New York. This research and manuscript preparation were supported in part by NSF Grant BNS 91-08719 and NIMH Grant MH-20752 to the University of California, San Diego. Reprints may be obtained from Edmund Fantino, Department of Psychology, University of California-San Diego, La Jolla, California 92093-0109.

reinforcement experienced more frequently has more impact on the behavior on which it is contingent. Moreover, it permits the equation to reduce to the familiar matching law (Herrnstein, 1970) when the durations of the terminal links are zero ($t_L = t_R = 0$).

Note that when either outcome represents an increase in average delay to reinforcement (either $t_L > T$ or $t_R > T$), Equation 2 requires the subject to respond exclusively on the key leading to the other outcome. In standard concurrent-chains procedures, predictions for exclusive preference have been supported (e.g., Fantino, 1969; Fantino & Davison, 1983). This prediction of exclusive preference is particularly relevant for successive choice procedures (used in several of the studies cited below) in which the subject may reject the less profitable outcome in the choice phase. The DRT specifies when the less profitable outcome should be rejected. Predictions of exclusive preference with the successive-encounters procedure have also been supported (e.g., Abarca & Fantino, 1982; Fantino & Abarca, 1985).

One feature of DRT is that the predictions of Equation 2 are based on scheduled values and may be specified precisely before a single data point has been collected. In general, we find this approach potentially more useful than one that may derive predictions from the data only after they have all been collected and analyzed. On occasion, however, especially in cases of extreme preference, obtained values of T differ substantially from the arranged or scheduled values. In such cases, better fits to the data may be obtained by employing obtained values (e.g., see Fantino, Freed, Preston, & Williams, 1991, p. 182, pp. 185–186).

Although the focus of this review is on the utility of DRT in accounting for choice in a variety of settings, we should also point out an important limitation. DRT was developed to account for choice with VI schedules. But it is well known that variable schedules are not functionally equivalent—as measured in choice procedures—to fixed schedules with comparable mean interreinforcement intervals. Thus formulations such as Equation 2 should not be expected to apply to schedules other than VI in any precise fashion. Accurate ordinal predictions should still be attainable, however. For a review of these issues, see Fantino and Naravick (1974) and Navarick and Fantino

(1974, 1975); for a more optimistic view, see Mazur (1984).

It should be noted that the fundamental notion of DRT is expressed by Equation 1 (i.e., in the expression of the delay-reduction kernel). Equation 2 predicts how conditioned reinforcement, expressed in terms of delay reduction, and primary reinforcement combine to account for preference in concurrent and concurrent-chains schedules. Modification of Equation 2 would not necessarily require revision of Equation 1.

We will review (a) the recent support for DRT in comparison to other models of choice, (b) comparisons to other models of conditioned reinforcement, and (c) our recent investigations of the contribution of the relative rate of conditioned reinforcers to preference.

Delay Reduction and Other Models of Choice

DRT has been supported in cases in which its predictions have been compared to predictions from competing viewpoints. For example, Dunn and Fantino (1982) pitted delay reduction against rate of reinforcement (t_x) as potential controlling variables in a concurrent-chains experiment and found that rate of reinforcement accounted for choice when and only when its predictions were consistent with those of DRT. In testing their three-alternative version of Equation 2, Fantino and Dunn (1983) showed that Luce's choice axiom (Luce, 1977), also known as the "independence from irrelevant alternatives" axiom of formal choice theories in economics and psychology, was consistent with choice when and only when its predictions were consistent with those of DRT.

More recently, LaFiette and Fantino (1989) have shown that DRT makes accurate predictions under radically different deprivation conditions (i.e., in both open and closed economies; after Hursh, 1980). Two recent studies (Dunn & Spetch, 1990; Spetch, Belke, Barnett, Dunn, & Pierce, 1990) have shown how DRT may be extended to findings of suboptimal choice in concurrent-chains schedules with uncertain outcomes. Finally, Fantino and Preston (1988) have applied DRT successfully to a foraging analogue in which the following counterintuitive prediction was supported: As the less profitable of two outcomes was encountered more frequently (with the absolute encounter rate for the more profitable kept

constant), there came a point at which subjects accepted it less frequently (i.e., greater accessibility led to lesser acceptability).

Some of the other predictions that may be derived from the optimal diet model (or classic optimal foraging theory) and from DRT (as expressed generally by Equation 1)—which Fantino and Abarca (1985) have shown to be equivalent—and that have been confirmed in our laboratory include:

1. As search duration (initial-link duration) is increased, birds shift from rejecting to accepting the less profitable of two outcomes at precisely the duration required by the models (Abarca & Fantino, 1982).

2. As equal outcome (terminal-link) durations are increased, pigeons shift from accepting to rejecting the less profitable of two outcomes (Ito & Fantino, 1986).

3. In choice between a lean schedule always leading to food and a rich schedule leading to food on only a percentage of food trials, pigeons preferred whichever alternative provided the higher overall mean rate of reinforcement (Abarca, Fantino, & Ito, 1985).

4. Changing accessibility of the more profitable alternative has a greater effect on choice than changing accessibility of the less profitable alternative (Fantino & Abarca, 1985).

5. Preference for the more profitable alternative decreases as travel time between alternatives increases (i.e., pigeons become less selective) (Fantino & Abarca, 1985).

6. Increased accessibility of the less profitable alternative leads to decreased acceptability of that alternative when accessibility is manipulated by varying the search time leading to the less profitable alternative (Fantino & Preston, 1988).

Finally, the results of a current series of experiments with both pigeons and teenaged humans appear to support predictions of the simultaneous-encounter model of foraging proposed by Engen and Stenseth (1984). Preliminary data were presented in Fantino and Preston (1989) and will not be discussed here.

Delay Reduction and Other Models of Conditioned Reinforcement

In a broad sense, every contemporary model of concurrent-chains performance assumes that preference is a function of two fundamental variables. The first is the rate of reinforcement

provided by each of the choice schedules making up the concurrent-chains procedure. The second is the conditioned-reinforcement value of each of the terminal links. Although there are differences in the ways the models have conceptualized these variables, there is general agreement about how the variables combine to produce preference. In a general way, each model can be represented as

$$\frac{B_L}{B_R} = \frac{R_L}{R_R} \cdot \frac{V_L}{V_R}, \quad (3)$$

where R_L and R_R represent the rates of reinforcement provided by the two alternatives, and V_L and V_R represent the terminal-link values.

The determination of the conditioned-reinforcement value of the terminal links (i.e., V_L and V_R) in concurrent chains has been somewhat controversial, each extant model having made unique assumptions about the determinants of conditioned-reinforcement value. Even so, each model has made one of two fundamental assumptions about the source of terminal-link values. Most models (e.g., Davison, 1987; Davison & Temple, 1973; Killeen, 1982) assume that the reinforcing values of the terminal-link stimuli are a function *solely* of the delay to primary reinforcement (in this case food) in their presence. Thus, they predict that the value of a terminal-link stimulus is determined independently of the other simple schedules making up the concurrent-chains procedure. The delay-reduction model, however, argues that the value of a food-associated stimulus depends as well upon the overall average time to food. For two stimuli of unequal duration (e.g., associated with VI 10-s and VI 20-s schedules), their relative values should depend upon the overall expected delay to food. If food presentation is relatively infrequent, say every 500 s, then the conditioned-reinforcement values of the two would be very similar (delay reductions of .98 and .96, respectively). If food presentations are relatively frequent, say every 40 s, then the conditioned-reinforcement values of the two would be more dissimilar (delay reductions of .75 and .50, respectively). Thus, the less frequent food is overall, the higher and more similarly valued are all food signals. The more frequent food is overall, the lower valued are all food signals, and the more discrepant (e.g., Fantino, 1969).

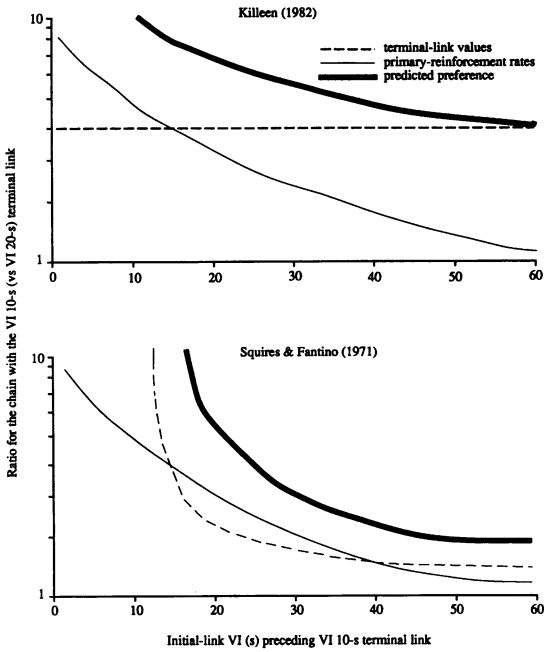


Fig. 1. The predictions of incentive theory (top) and delay-reduction theory (bottom) as the initial link preceding the shorter (richer) outcome is varied. See text for details.

The DRT, then, predicts that the value of a terminal-link stimulus is a joint function of all schedule parameters that contribute to the overall delay to primary reinforcement in the situation

$$V_L = \frac{T - t_{2L}}{T}, \quad T = f(t_{1L}, t_{1R}, t_{2L}, t_{2R}), \quad (4)$$

where t_{1L} , t_{1R} , t_{2L} , and t_{2R} represent the average delays in the left and right initial links and left and right terminal links, respectively.

It would seem to be a simple matter to choose between these two general conceptions of the determinants of the conditioned-reinforcement value of the terminal link. In practice, though, it has not been easy, because overall preference functions tend to obscure the separate purported effects of the underlying determinants of preference. This can be seen by graphically separating the predicted contributions of the value (i.e., V_L and V_R) and frequency (i.e., R_L and R_R) components of the several models. For example, Figure 1 shows the predictions of DRT (Squires & Fantino, 1971) and incentive theory (Killeen, 1982) of the effects of varying the initial link preceding the shorter of two terminal links in a concurrent-chains schedule

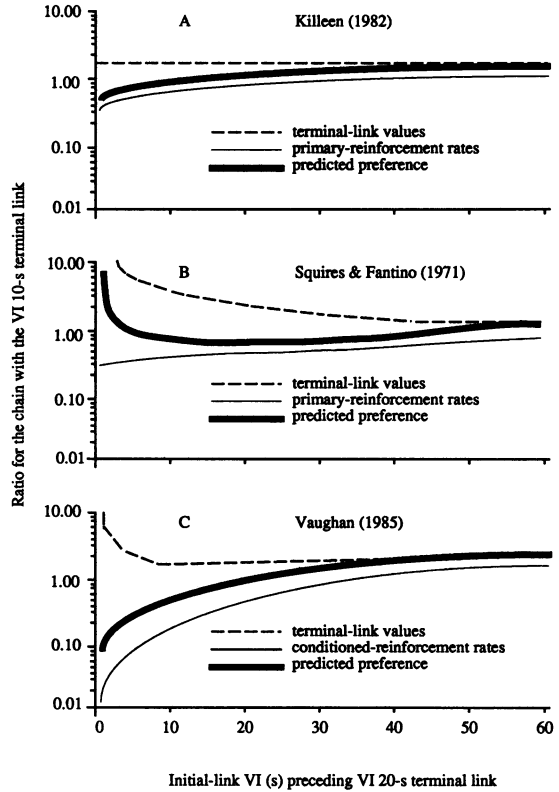


Fig. 2. The predictions of incentive theory (top), delay-reduction theory (middle), and melioration (bottom) as the initial link preceding the longer (poorer) outcome is varied. See text for details (from Preston & Fantino, 1991).

with VI 10-s and VI 20-s terminal links. For each model, three separate predicted functions are plotted: the change in overall preference, the change in the relative rate of primary reinforcement, and the change in the relative values of the terminal links. Because both models assume that response ratios should be proportional to the ratio of *primary* reinforcement rates, the functions for the relative rate of reinforcement are identical. Both models predict that preference changes, in part at least, because the ratio of primary-reinforcement rates is decreasing. The critical distinction between the models can be seen in the functions for the terminal-link values. According to incentive theory, the relative values of the terminal links are unchanged by the initial-link schedules—thus the flat function relating the terminal-link values to the varied initial link. In contrast, DRT treats the values of the terminal links as a joint function of their durations and the temporal context in which they occur. DRT

predicts, therefore, that increasing the initial-link schedule decreases the relative value of the terminal link through the resultant increase in the overall average delay (i.e., T) to primary reinforcement. Thus, the models make similar qualitative predictions about the changes in overall preference even though they differ as to what determines the function. Preference is decreasing because either (a) the ratio of primary-reinforcement rates *and* the ratio of conditioned-reinforcement values are decreasing, or (b) only the ratio of primary-reinforcement rates is decreasing.

In order to differentiate the two conceptions, it is necessary to find conditions in which the effects of changes in the terminal-link values are not also potentially caused by changes in the relative reinforcement rates. Consider the effect of varying the initial link preceding, not the VI 10-s (i.e., shorter) terminal link, but rather the VI 20-s (i.e., longer) terminal link. As the initial-link VI requirement is increased, the rate of reinforcement decreases on the VI 20-s alternative. The top two graphs of Figure 2 show the predictions of Killeen (1982) and Squires and Fantino (1971). Again, separate functions are shown for overall preference, the rates of reinforcement, and the values of the terminal links. Delay-reduction theory predicts that while the ratio R_L/R_R is increasing, the ratio V_L/V_R is decreasing—that is, changing in the opposite direction. The decrease in the ratio of conditioned-reinforcement values is due to the increase in the average delay to primary reinforcement. The net predicted response ratios are the products of the two functions, a bitonic function of the initial link preceding the VI 20-s terminal link. Killeen (1982), on the other hand, predicts that the terminal-link values do not change as a function of the varied initial link, and therefore predicts a monotonically increasing function resulting entirely from the changing ratio of primary-reinforcement rates.

To test these predictions, Preston and Fantino (1991, Experiment 1) assessed pigeons' preferences for VI 10-s versus VI 20-s terminal links as the initial link preceding the VI 20-s terminal link was varied. The initial link preceding the VI 10-s terminal link was VI 60 s. Figure 3 shows preference for the VI 10-s terminal link averaged over the last five sessions for each subject. Data are plotted as response ratios for the VI 10-s schedule—that is, initial-link responses on the VI 10-s key

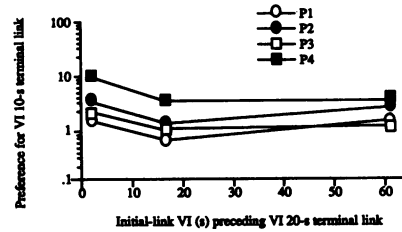


Fig. 3. Preference for the shorter (VI 10 s) of two terminal links as a function of the initial-link VI schedule preceding the longer (VI 20 s) of two terminal links for each of 4 pigeons (from Preston & Fantino, 1991).

divided by the initial-link responses on the VI 20-s key. For each of 4 pigeons, response ratios were a bitonic function of the initial link leading to the VI 20-s terminal link. As the initial-link schedule leading to the VI 20-s terminal link increased from fixed interval (FI) 1 s to VI 14 s to VI 60 s, preference for the VI 10-s terminal link first decreased and then increased. Averaged across subjects, preferences for the VI 10-s schedule were 4.43, 1.32, and 1.86, respectively, when the initial-link schedules were FI 1 s, VI 14 s, and VI 60 s. Preston and Fantino noted that the FI 1-s initial-link schedule imposes limits on the number of responses to that alternative but pointed to evidence from related procedures (Fantino & Davison, 1983) that corroborate this pattern of results in situations in which the potential artifact does not apply. If the values of the terminal links were a constant function of their associated schedules, as suggested by incentive theory, then preference should have been a monotonic function of the varied initial-link schedule, reflecting, in effect, matching to the frequencies of different amounts of reinforcement (cf. Catania, 1963; Dunn, 1982). Instead, these results support the conception of conditioned-reinforcement value embodied in DRT. According to DRT, the conditioned reinforcing value of a food-paired stimulus is not properly understood as being determined solely by the delay to food in its presence. Rather, the values of the terminal links are jointly determined by their associated schedules and the overall context (i.e., T) in which they occur. Consistent with this view, preference appeared to be the result of two opposing influences: the increasing ratio of primary reinforcement rates and the decreasing ratio of conditioned-reinforcement values.

As discussed by Williams (1988), there is additional support for the general condition-

ing view proposed by the delay-reduction hypothesis. Because classical conditioning is generally assumed to be the process underlying the development of conditioned reinforcers (cf. Ellison & Konorski, 1964; Mackintosh, 1974; Skinner, 1938, p. 245), any model of conditioned reinforcement must necessarily predict the basic relations found to be important in classical conditioning. The context effect predicted by the delay-reduction hypothesis is well documented in classical conditioning (Gibbon, Baldock, Locurto, Gold, & Terrace, 1977; Gibbon & Balsam, 1981; Terrace, Gibbon, Farrell, & Baldock, 1975). The value (eliciting efficacy) of a Pavlovian conditioned stimulus (CS) has been shown to be a function of the *ratio* of the interfood interval to the trial duration. Consistent with the arguments presented here, Gibbon *et al.* argued that earlier accounts formulated in terms of absolute trial durations (Ricci, 1973) fundamentally misrepresent the conditioning situation. The effect of pairing a given-duration CS with food depends on the CS duration *in relation to* the average interfood interval. Thus, the delay-reduction effect is not limited to the development of instrumental conditioned-reinforcement strength or to situations involving concurrent chains. Instead, stimulus conditioning seems to be generally dependent upon the overall context of reinforcement.

Rate of Reinforcement in Concurrent Chains

Thus far it has been argued that the context effect, as formulated in the delay-reduction hypothesis, must be a central component of any account of conditioned reinforcement. Although no other contemporary model has explicitly incorporated this effect, Preston and Fantino (1991) showed that the melioration model proposed by Vaughan (1985) is essentially identical to the delay-reduction hypothesis in terms of their predictions about conditioned-reinforcement value. The bottom two graphs in Figure 2 show the predictions of Squires & Fantino (1971) and Vaughan (1985) for Preston and Fantino's Experiment 1. These two models differ, not in terms of their predictions of the effects of terminal-link values but rather in terms of their predictions of the effects of the ratio of reinforcement rates. Whereas Squires and Fantino (1971) predict preference as a function of the ratio of *primary-*

reinforcement rates, Vaughan (1985) predicts preference as a function of the ratio of *conditioned-reinforcement* rates. Because the latter changes more quickly with variations in initial-link schedules than does the former, the terminal-link values exert less of an effect in Vaughan's (1985) model. The result is that Vaughan, like Killeen (1982), predicts a monotonically increasing function, but for entirely different reasons. Rather than directly considering the difference between the models of Squires and Fantino (1971) and Vaughan (1985), consider instead a related melioration model. Luco (1990) derived a choice model from the assumptions of melioration that has the same value terms as delay reduction and differs only in the reinforcement-rate terms multiplying the ratio of values:

$$\frac{B_L}{B_R} = \frac{(1/t_{1L}) \cdot (T - t_{2L})}{(1/t_{1R}) \cdot (T - t_{2R})}. \quad (5)$$

The corresponding DRT equation is:

$$\frac{B_L}{B_R} = \frac{\frac{1}{(t_{1L} + t_{2L})} \cdot (T - t_{2L})}{\frac{1}{(t_{1R} + t_{2R})} \cdot (T - t_{2R})}. \quad (6)$$

Like Vaughan, Luco assumed that preference should be proportional to the ratio of the rates of *conditioned reinforcement* rather than *primary reinforcement*. Also like Vaughan, Luco predicts a monotonically increasing function for the conditions of Preston and Fantino. However, neither model is fundamentally challenged by the results of Preston and Fantino. If it is assumed that the sensitivity of the rates of conditioned reinforcement need not be perfect, Luco's equation can be modified by raising the ratio of conditioned-reinforcement rates to a power less than 1.0, thereby increasing the relative influence of the terminal-link values. This simple modification allows Luco and Vaughan to predict the results of Preston and Fantino. Whether preference in concurrent chains is determined by the rates of conditioned reinforcement, the rates of primary reinforcement, or both, is still an open question.

We have addressed this issue in two procedures. First, Fantino *et al.* (1991) recently completed a study with two broad aims: (a) to assess whether or not frequency of conditioned

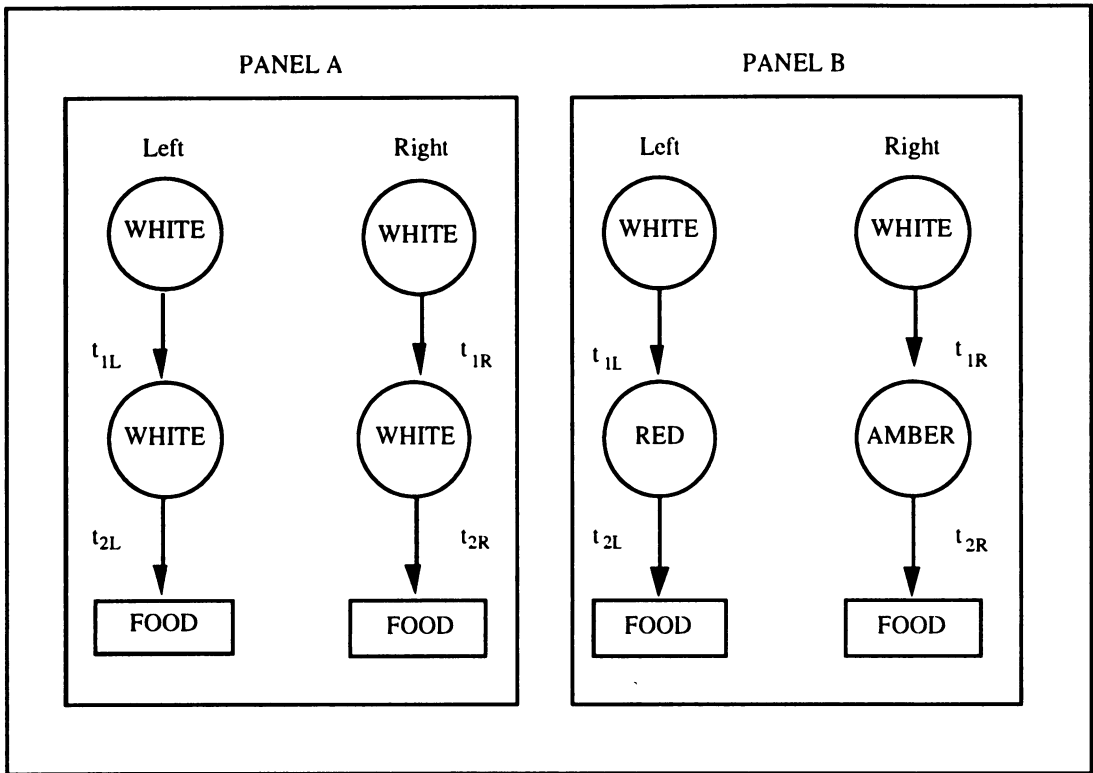


Fig. 4. The concurrent-tandem and concurrent-chains procedures. Panel A illustrates the sequence of events in a concurrent tandem, in which the same stimulus is present on each key throughout. Panel B shows the sequence of events in a concurrent chain. Note that entry into each terminal link in Panel B is signaled by a unique stimulus. During both choice and outcome phases of one schedule, the other schedule remains operative in both the chain and tandem procedures (from Fantino et al., 1991).

reinforcement affects choice independently of its role in affecting the absolute rates of primary reinforcement (r_L and r_R) and (b) to assess the relative contributions of the delay-reduction and primary-reinforcement factors in Equation 2, that is, $(T - t_x)$ and r_x , respectively.

Conditions in the study by Fantino et al. (1991) involved comparisons of modified concurrent-chains schedules and comparable yoked concurrent-tandem schedules. In typical concurrent-chains schedules, entry into one terminal link is accompanied by the darkening of the other response key, which then remains inoperative until reinforcement has been delivered. If a concurrent-tandem schedule were to operate in this manner, however, the darkening of one response key would serve as a cue for terminal-link entry, thereby converting the tandem schedule to a chained schedule. To retain the essential feature of a tandem sched-

ule—that no stimulus change is correlated with the onset of a new link—the yoked concurrent-tandem schedules used in these comparisons were independent and operative throughout (i.e., when the subject entered the terminal link on one response key, the other response key remained lit and operative). In order to maintain comparability with the tandem schedules, therefore, the concurrent-chains schedules were also independent and operative throughout (of course, a stimulus change occurred on a response key as the subject entered a terminal link, the essential feature of a chain schedule). This type of modified concurrent-chains schedule was used by Fantino and Duncan (1972) and is illustrated in Figure 4.

Two sets of conditions were examined. In both, the initial link was shortened on only one of two concurrent-chains schedules and on only one of two corresponding concurrent-tandem schedules. Shortening the initial link in-

creases the rate of primary reinforcement on both the chained and tandem schedules. This same manipulation, however, will affect the rate of conditioned reinforcement only on the chained schedule because distinctive terminal-link stimuli—the putative conditioned reinforcers—do not occur in tandem schedules. Thus, if rate of conditioned reinforcement does indeed affect choice, preference for the alternative associated with the shorter initial link should be greater on the chained schedule than on the equivalent tandem schedule. On the other hand, if the frequency of conditioned reinforcement is effective only through changing the overall rate of primary reinforcement (r_L and r_R in Equation 2), then preference on the chained and tandem schedules should be equivalent. In the first experiment the terminal-link durations were equal in all conditions (i.e., $t_L = t_R$ in Equation 2). Thus, $(T - t_L) = (T - t_R)$ and, according to Equation 2, choice should depend only on the overall rates of primary reinforcement. In terms of the chained and tandem comparisons, therefore, preference should be roughly equivalent. If choice were consistent with these predictions of Equation 2, the results would imply that frequency of conditioned reinforcement is effective only through changing the overall rate of primary reinforcement (or that the terminal-link stimuli are not conditioned reinforcers).

When the initial link leading to one of two equal terminal links was shortened (e.g., from VI 60 s to VI 10 s, or for 2 subjects, from VI 120 s to VI 10 s) while the initial link leading to the other terminal link was left unchanged (at VI 60 s and VI 120 s, respectively), did preference increase more in the chained schedule than in the yoked-tandem comparison? The mean increases in the chained-schedule condition (averaged across replications for the 4 subjects exposed to the chained conditions twice) were compared to those in the yoked-tandem-schedule condition for each of 7 subjects. For only 3 of the 7 subjects was the increase in preference greater in the chained-schedule conditions than in the tandem schedule conditions. The mean increase across 7 subjects was .07 for the chained schedule conditions (from .58 to .65) and .08 for the yoked-tandem-schedule conditions (from .52 to .60). Thus, there was no suggestion that the six-fold increase in rate of conditioned reinforcement (a 12-fold increase

for 2 subjects) increased preference beyond the increase attributable to the accompanying (though relatively smaller) increase in rate of primary reinforcement that also occurred in the tandem schedules.

These results suggest that the frequency of conditioned reinforcement does not affect choice directly, in keeping with delay-reduction theory. There was no differential delay reduction—that is, $(T - t_L) = (T - t_R)$ in Equation 2—and choice appeared determined only by the relative interreinforcement intervals. When the terminal links are unequal, however, greater delay reduction is associated with the shorter terminal link. As a result, preference for the shorter terminal link should be greater in the chained-schedule than in the corresponding tandem schedule (in which there is no delay reduction). Thus, whereas delay-reduction theory predicts no difference in preference when comparing equivalent chained and tandem schedules when the terminal links are equal, clear differences are predicted when the terminal links are unequal. In fact, in a second set of conditions with unequal terminal links, for each of 4 subjects the choice proportion in each of the two chained-schedule conditions was higher than the corresponding choice proportions in the yoked-tandem-schedule conditions. In one condition, in which both the chained and yoked tandem schedules arranged equal initial-link schedules and unequal terminal-link schedules, preference for the shorter terminal link was greater in the chained schedule for each of the 4 pigeons (.83 vs. .69, .78 vs. .66, .82 vs. .52, and .77 vs. .61). In the other condition, in which the initial and terminal links were both unequal, preference was again greater in the chained schedule condition for each of the subjects (.97 vs. .81, .93 vs. .87, .95 vs. .71, and .92 vs. .77). The actual schedule values used, complete results from each of these experiments, and a summary of the quantitative consistency of the data with Equation 2 are found in Fantino *et al.* (1991, Tables 1–5 and text).

To summarize, according to delay-reduction theory, when the outcomes chosen are equal, choice should depend only on rate of primary reinforcement (r_x in Equation 2) because delay reduction is not a factor ($T - t_L = T - t_R$). One implication is that rate of conditioned reinforcement should not affect choice. These predictions were confirmed: Choice was com-

parable for comparable chained and tandem schedules even when the schedules were altered so as to provide a six-fold increase in rate of conditioned reinforcement on the chained as opposed to the tandem schedule. When the terminal links were unequal, choice should then depend upon both rate of primary reinforcement and relative delay reduction. Thus, larger preferences should occur for the shorter terminal link in the chained schedules than in the tandem schedules. This prediction was also confirmed.

Royalty, Williams, and Fantino (1987) and Williams and Dunn (1991) have shown that the terminal-link stimuli in concurrent-chains schedules appear to function as conditioned reinforcers. Nonetheless, the results of the above experiments suggest that increasing the frequency of these stimuli does not affect choice independently of the effects of such changes on the interreinforcement interval. This is a somewhat unsettling conclusion. We should point out that although the results just discussed are entirely compatible with the notion that frequency of conditioned reinforcement does not affect choice independent of the effects of frequency of primary reinforcement, they do not necessarily rule out models incorporating frequency of conditioned reinforcement as a critical independent variable.

In the second series of experiments, we are investigating (together with Bertram Ploog and Jay Goldschmidt) preference in concurrent-chains procedures in which frequency of conditioned reinforcement is held constant while frequency of primary reinforcement is varied and in which the opposite is true. Thus, results from these experiments will enable us to evaluate the relative efficacy of Equations 5 and 6 in accounting for choice. Specifically, should the delay-reduction kernel be multiplied by the rates of primary reinforcement (Equation 6) or by the rates of conditioned reinforcement (Equation 5), or are both necessary?

There have been prior attempts to separate the effects of conditioned reinforcement from those of unconditioned reinforcement. One type of study examined preference for conditioned reinforcers paired intermittently with primary reinforcers in concurrent-chains schedules (e.g., Schuster, 1969; Squires, 1972; both reviewed in Nevin & Mandell, 1978). These studies failed to demonstrate clear or sustained preferences for conditioned reinforcers. This find-

ing is consistent with DRT in that the putative conditioned reinforcers, although sometimes paired with primary reinforcement, were not correlated with a reduction in time to primary reinforcement. On the other hand, Nevin and Mandell obtained strong preferences for a conditioned-reinforcement alternative in a study with rats in which the putative conditioned reinforcers were correlated with a reduction in time to reinforcement.

In sum, the work presented here demonstrates the viability of delay-reduction theory. The delay-reduction concept has been extended to other domains, as described earlier. Delay reduction provides a successful description of several anomalous findings in the literature (e.g., preference for less reliable reinforcement). Counterintuitive predictions of delay-reduction theory have been supported in comparisons with other models of choice. Finally, we have outlined some of the concerns that promise to enliven the further exploration of the determinants of choice.

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